

# Synergy with new radio facilities: from LOFAR to SKA

Raffaella Morganti

ASTRON (NL) and Kapteyn Institute (Groningen)

# New generation radio telescopes

Major new capabilities of radio telescopes:

- ★ **large field of view** —→ Many sq deg in one pointing! with high spatial resolution
- ★ **broad instantaneous band** —→ HI over large redshift, spectral properties, magnetism
- ★ **fast response** —→ Transient events

**Commensality of the observations** → allow a variety of *different science using one pointing*

New possibilities for the science → but huge datasets and need for pipelines

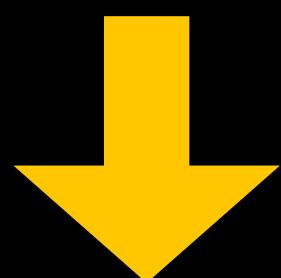
Availability of *ancillary data very important!*

Coordination with other facilities/telescopes essential for success

# New Radio Facilities

		Frequencies	Surveys?	Status
LOFAR	North	40 - 200 MHz	Yes	Operational Cycle 6
Apertif-WSRT	North	1.15 - 1.7 GHz	Yes	Close to completion Commissioning
MWA	South	74 - 230 MHz	Yes	Operational
ASKAP	South	0.7 - 1.8 GHz	Yes	Close to completion Commissioning
MeerKAT	South	0.6 – 1.0 GHz 1.0 – 1.7 GHz	Large areas, famous fields	Close to completion Commissioning

← HI  
← HI  
← HI



Square Kilometre Array - SKA

# Some new (low spatial resolution) surveys

	<b>Frequencies</b> <b>Resolution</b>	<b>Web site</b>	<b>References</b>
<b>MSSS:</b> Multifrequency Snapshot Sky Survey (MSSS)- LOFAR	150 MHz	<a href="http://vo.astron.nl/">http://vo.astron.nl/</a>	Heald et al. 2015 <a href="http://arxiv.org/abs/1509.01257">http://arxiv.org/abs/1509.01257</a>
<b>GLEAM:</b> The GaLactic and Extragalactic All-sky MWA survey	150MHz 2.5arcmin	<a href="http://mwatelescope.org/astronomers/public-data-release">http://mwatelescope.org/astronomers/public-data-release</a>	<a href="http://arxiv.org/abs/1505.06041">http://arxiv.org/abs/1505.06041</a> Wayth, et al. 2015
<b>TGSS - GMRT</b>	150MHz ~25 arcsec	<a href="http://tgssadr.strw.leidenuniv.nl/doku.php">http://tgssadr.strw.leidenuniv.nl/doku.php</a>	<a href="http://arxiv.org/abs/1603.04368">http://arxiv.org/abs/1603.04368</a> Intema et al. 2016

Observations often taken in different epochs to enable also search for transients

# The LOw Frequency ARray



High Band Antenna

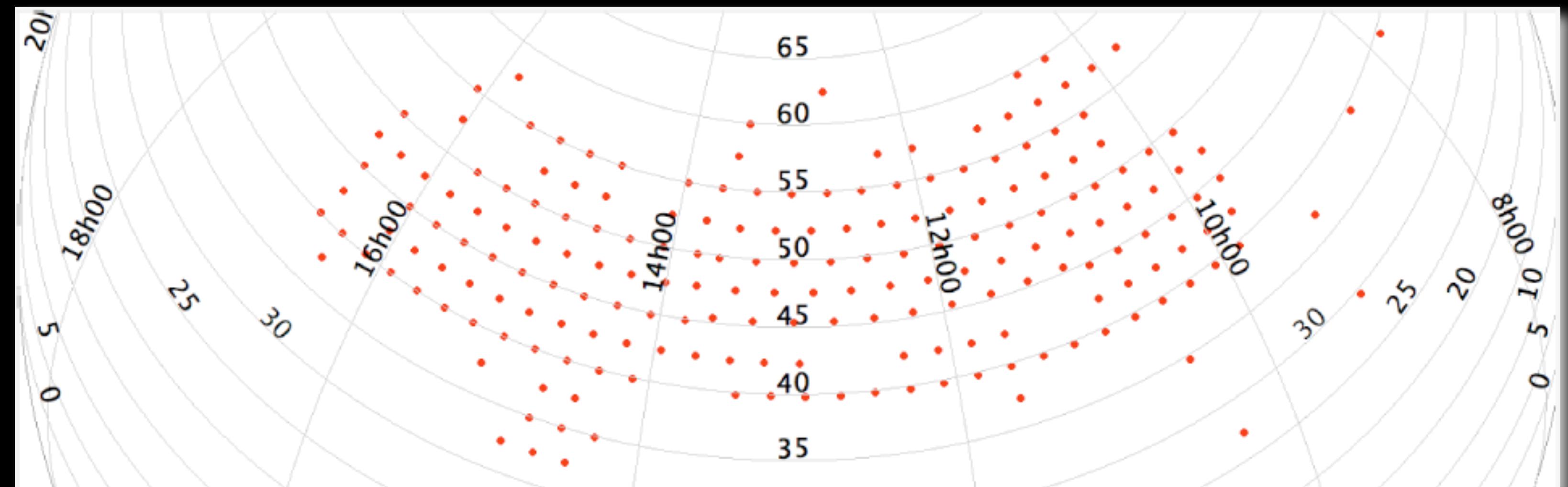


Low Band Antenna

- Unique because:
  - 38 stations in NL spread over  $\sim 100$  km
  - 12 international stations
  - ***high spatial resolution*** (arcsec to subarcsec) at low freq ( $\sim 40\text{-}200$  MHz) and ***large field of view***
- **Imaging surveys** Key Science Project → PI: Huub Rottgering
- **Transients** Key Science Project
  - PIs: Rob Fender, Ben Stappers, Ralph Wijers

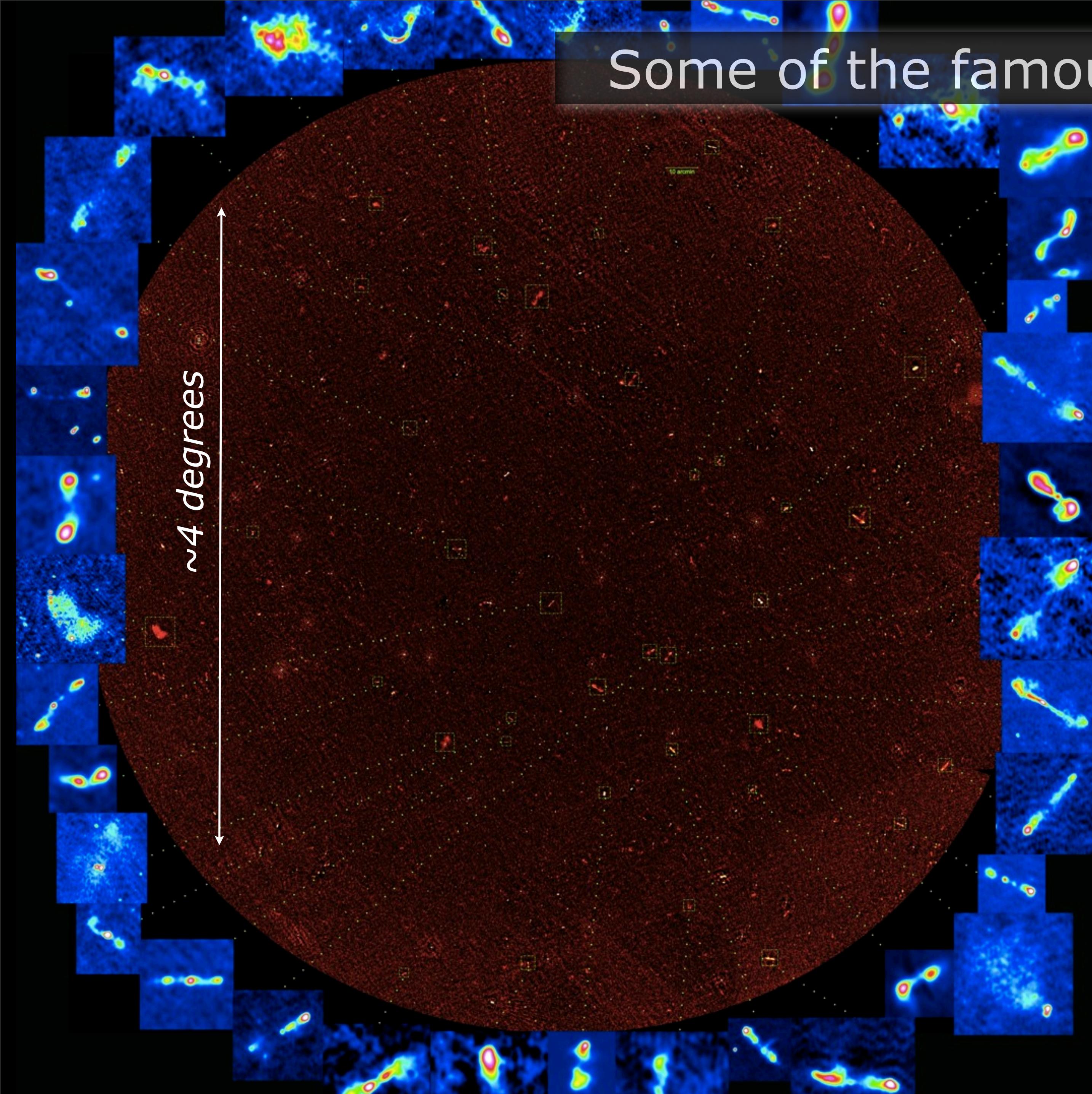
# LOFAR imaging SURVEYS

- PI: Huub Rottgering (Leiden)  
co-I: *Miley, Brugger, Brunetti, Best, Morganti, Jackson, White, Jarvis, Conway, Chyzy, Barthel, Lehnert*
- Goals @ 150MHz: **all northern sky**, 8h per pointing, **5" images with 100 μJy/beam noise**
- Entering production mode (leading the data reduction: Tim Shimwell, Leiden)  
→ *where are we now?* relatively easy to reach 20" HBA (@150MHz), major progress on the pipeline to reach higher resolutions; LBA (~60MHz) more difficult (calibration issues)



- synergy with (slow)transients  
→ *more than one observation per pointing in different epochs*

# Some of the famous fields first targets for LOFAR



Example of the Boötes field  
at 150MHz with 5" resolution

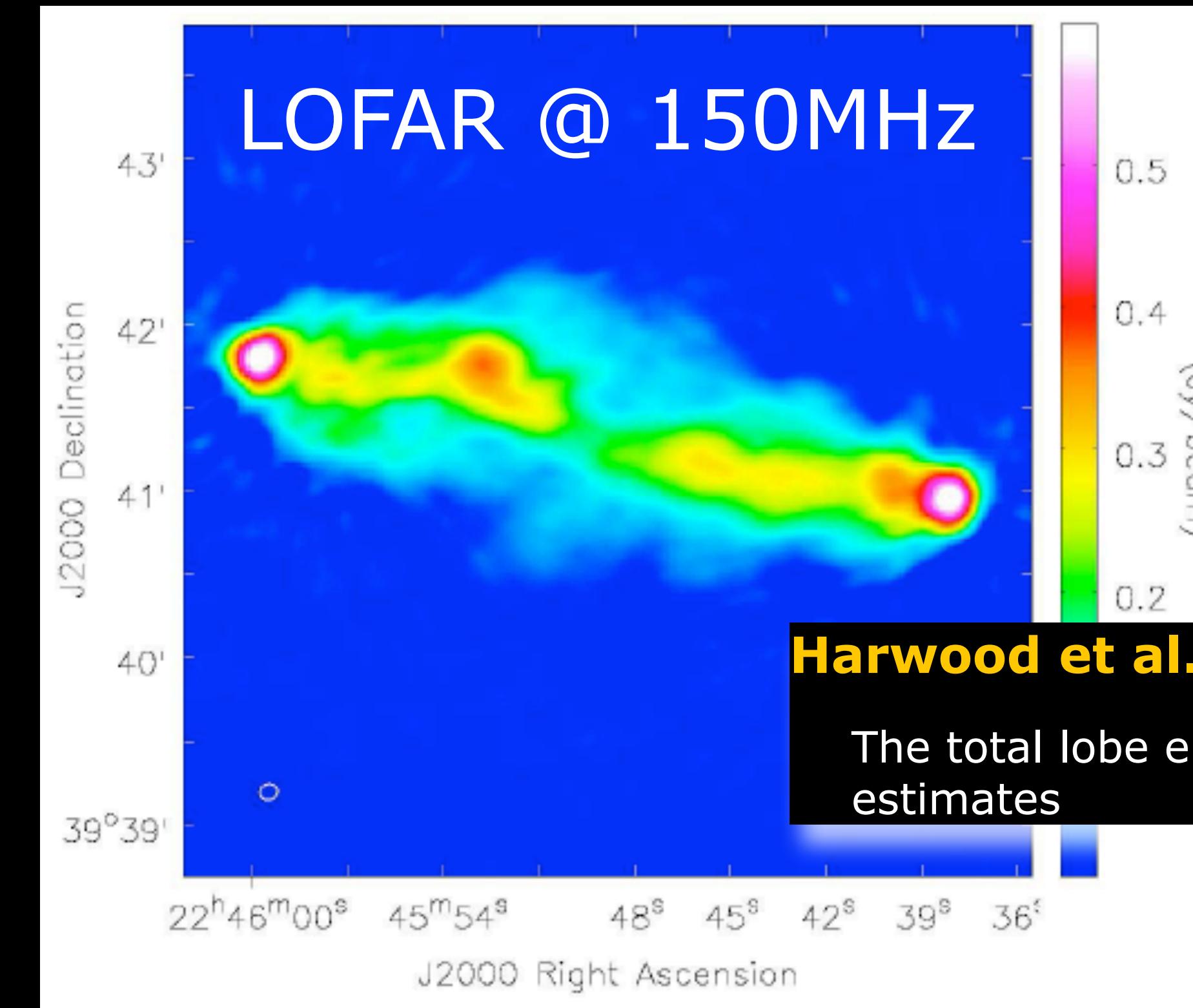
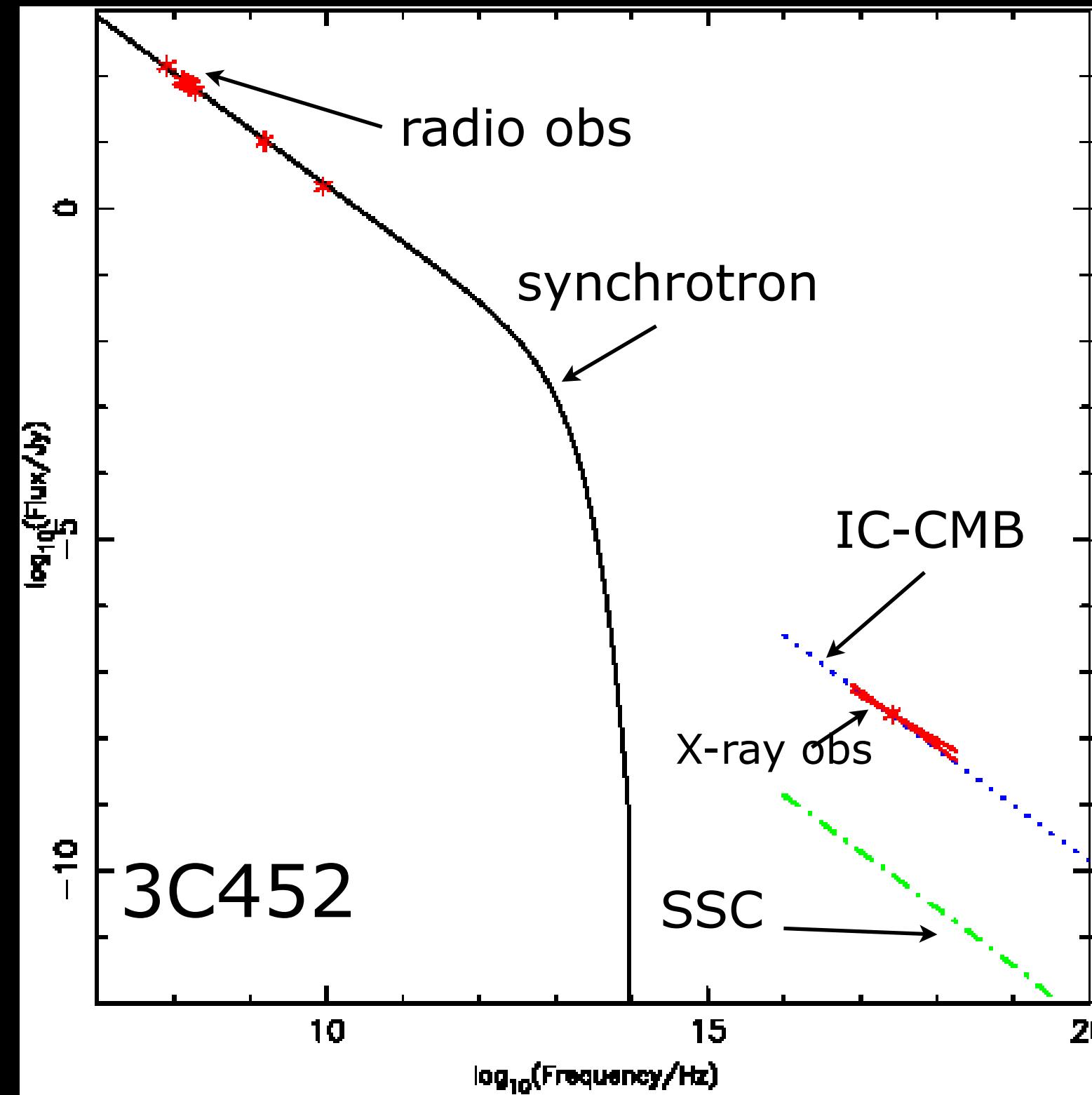
*Williams et al. MNRAS 2016  
astro-ph/1605.01531*

One pointing:  
6546 sources detected over  
an area of  $19\text{deg}^2$

**A number of famous fields done:**  
Lockman Hole (*Mahony et al.*), HETDEX  
(*Shimwell et al.*), XMM-LSS (*Best et al.*),  
Herschel-ATLAS (*Hardcastle et al.*) etc.

# Energetics of radio galaxies: combining X-ray and low-frequencies spectral information

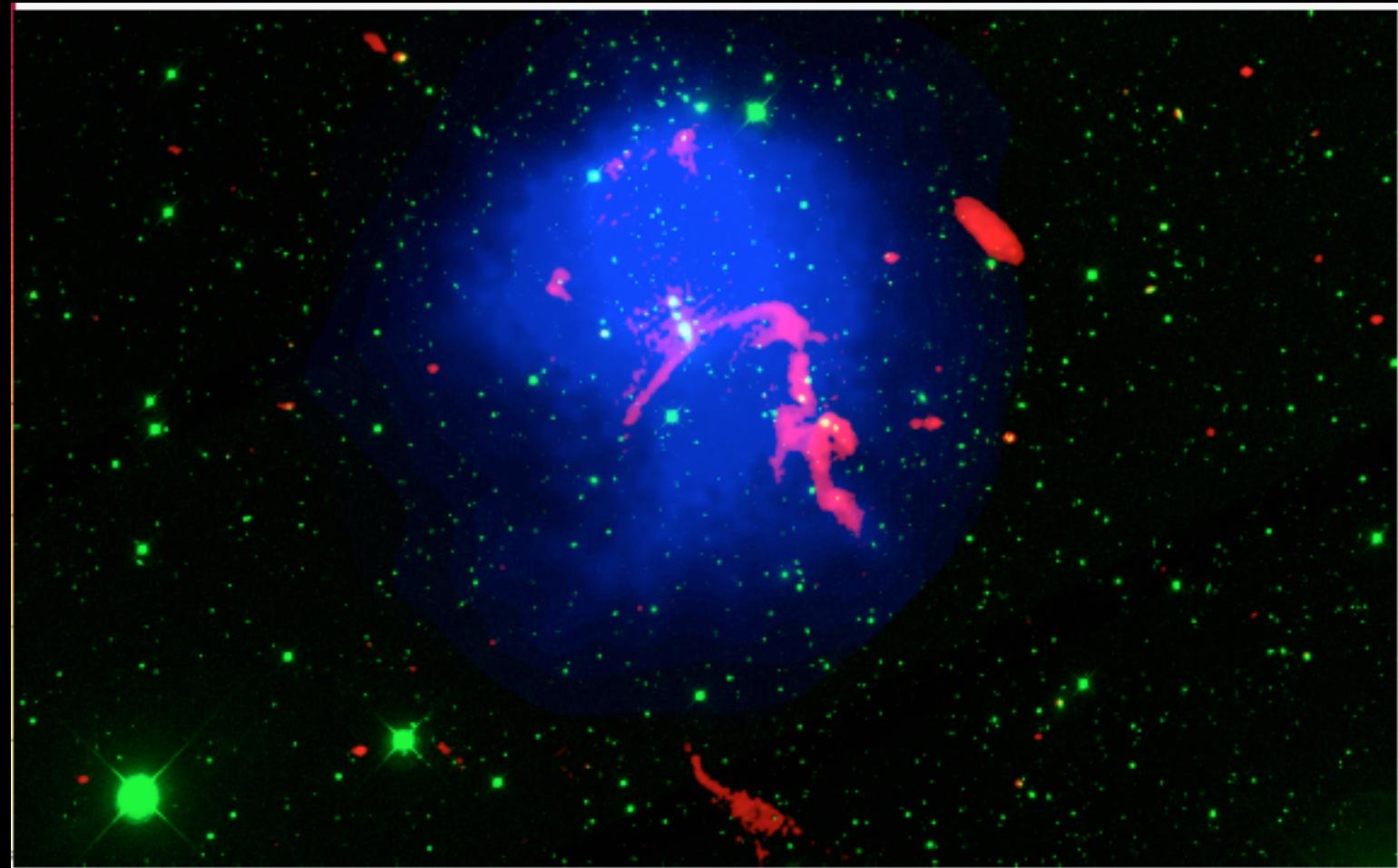
X-ray providing an independent way to derive the magnetic field strength (for IC process)  
→ need constraints for spectrum at low frequencies (seeds electrons)



**Characterise the entire radio galaxy/starburst population (not only the most powerful radio galaxies!)**

*Morganti, Hardcastle, Rottgering et al.*

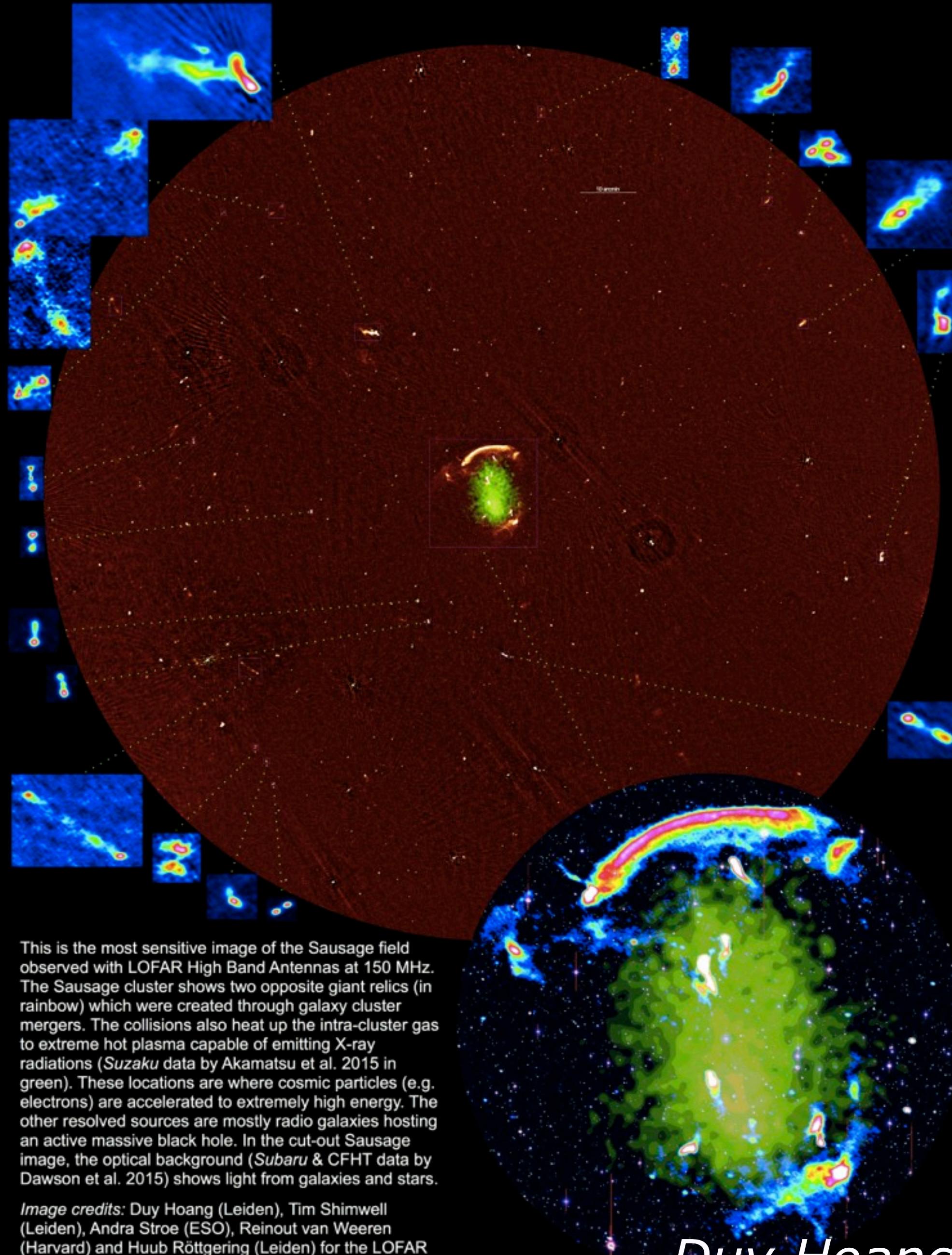
# Clusters and cluster relics



Abell 2034, Shimwell et al. 2016  
*astro-ph/1603.06591*

Searching for new clusters  
and cluster relics

LOFAR @ 150 MHz: the Sausage cluster



Brugger, Brunetti, Rottgering et al.

Duy Hoang et al. in prep

# LOFAR transients (<http://www.transientskp.org/>)

- **Transients** Key Science project → PI Rob Fender, Ben Stappers, Ralph Wijers

all time-variable astronomical radio sources, including pulsars, gamma-ray bursts, fast radio bursts, X-ray binaries, radio supernovae, flare stars, exoplanets.

## Including a Multi-Messenger Follow-Up Working Group

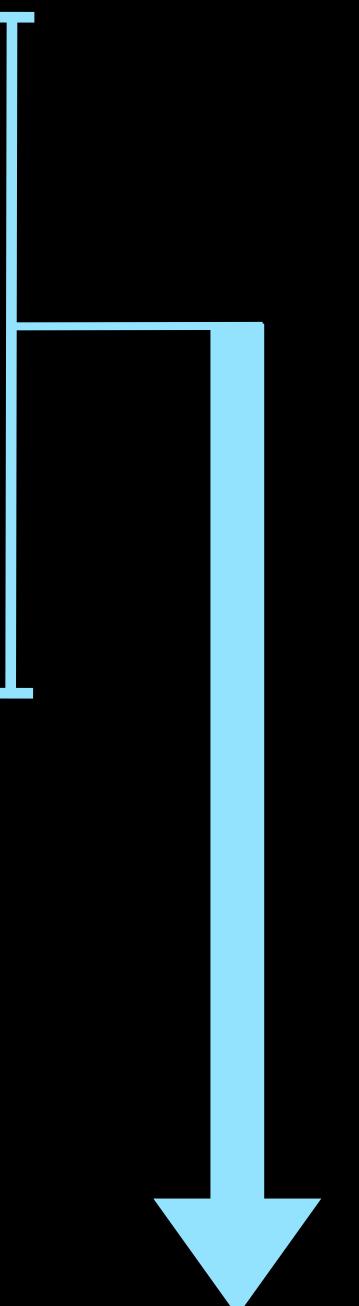
- in **imaging** → slow transients, fast transients (still to come)
- AARTAAC (will send real-time alert, PI: Ralph Wijers )

### **Amsterdam—ASTRON Radio Transients Facility and Analysis Centre**

<http://www.aartfaac.org> all sky monitor at low spatial resolution

- in **time-domain** → e.g. pulsars

*soon we will be able to trigger from radio transients and accurately locate their positions*

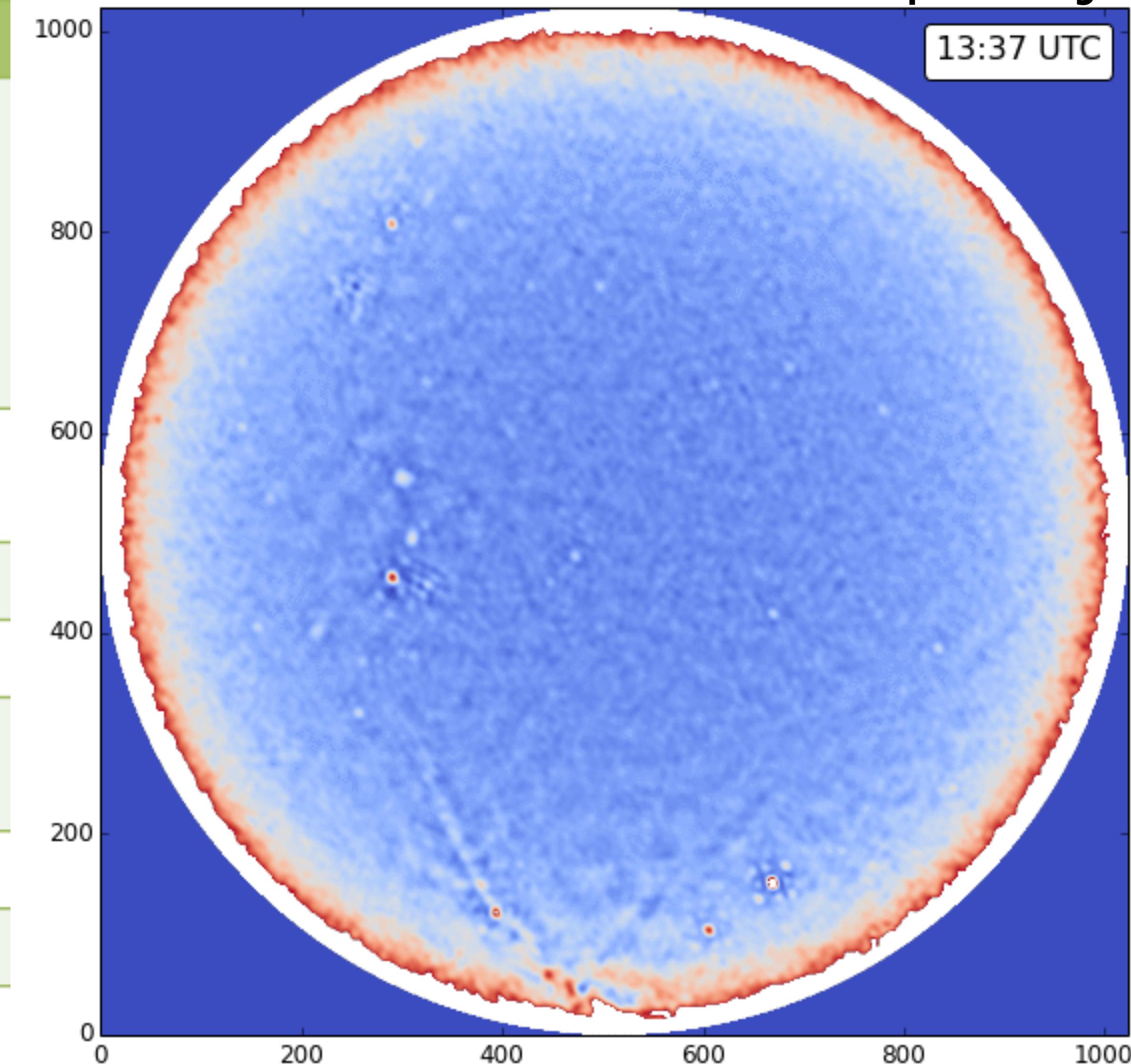


# AARTAAC – a real-time sky monitor

PI Ralph Wijers



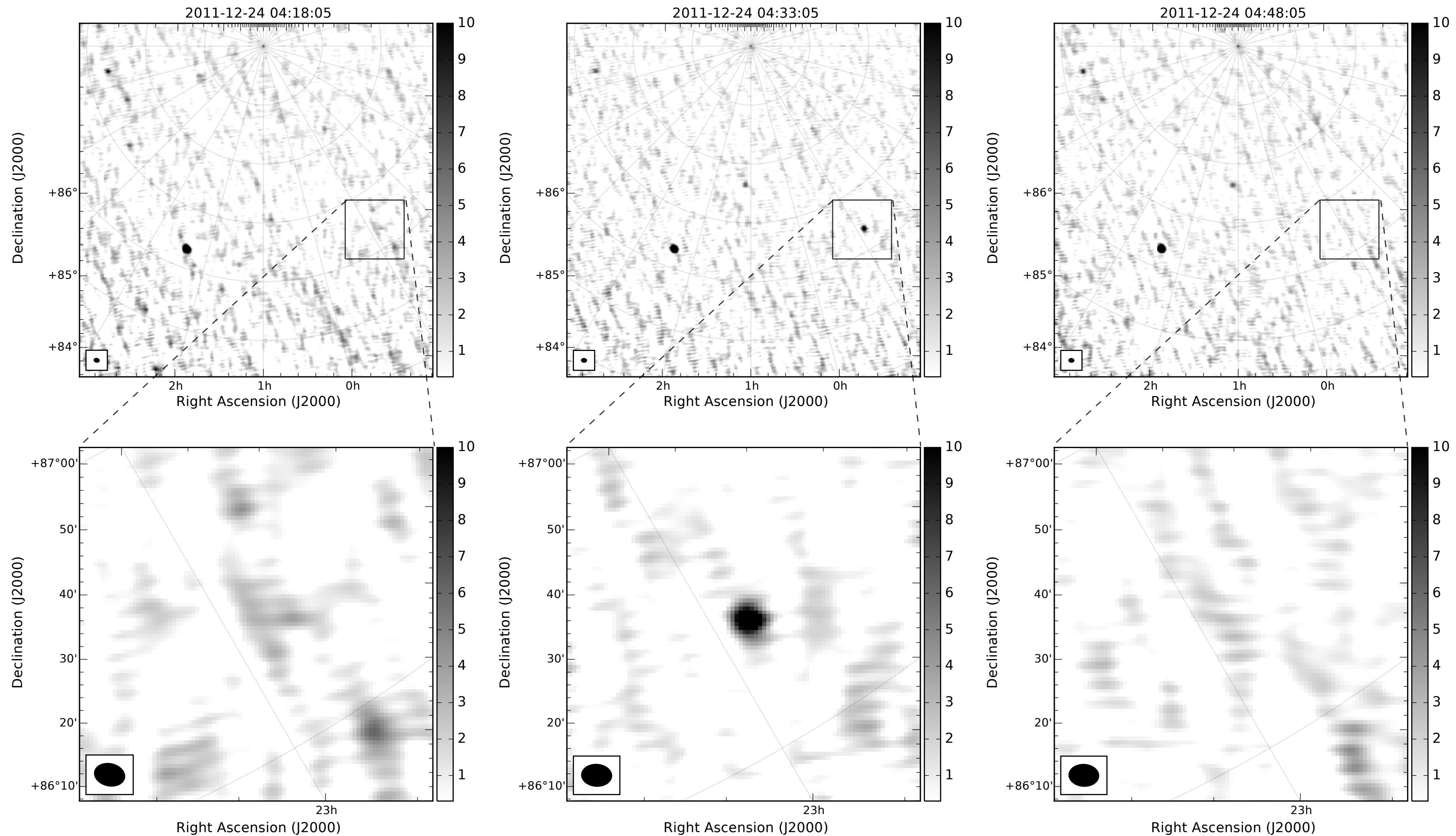
Array Elements	288 inverted V antennas
Freq. Range (MHz)	30-80
Field of View (sr)	$\pi$
Angular Resolution (arcmin)	60
Spectral Res. (kHz)	15
Temporal Res. (s)	1
Sensitivity (Jy)	40



Prasad et al. (2014), Cendes et al. (in prep)

Credit: Mark Kuiack

# The first low frequency transient (LOFAR NCP)



Frequency 57 MHz  
Duration ~4 minutes

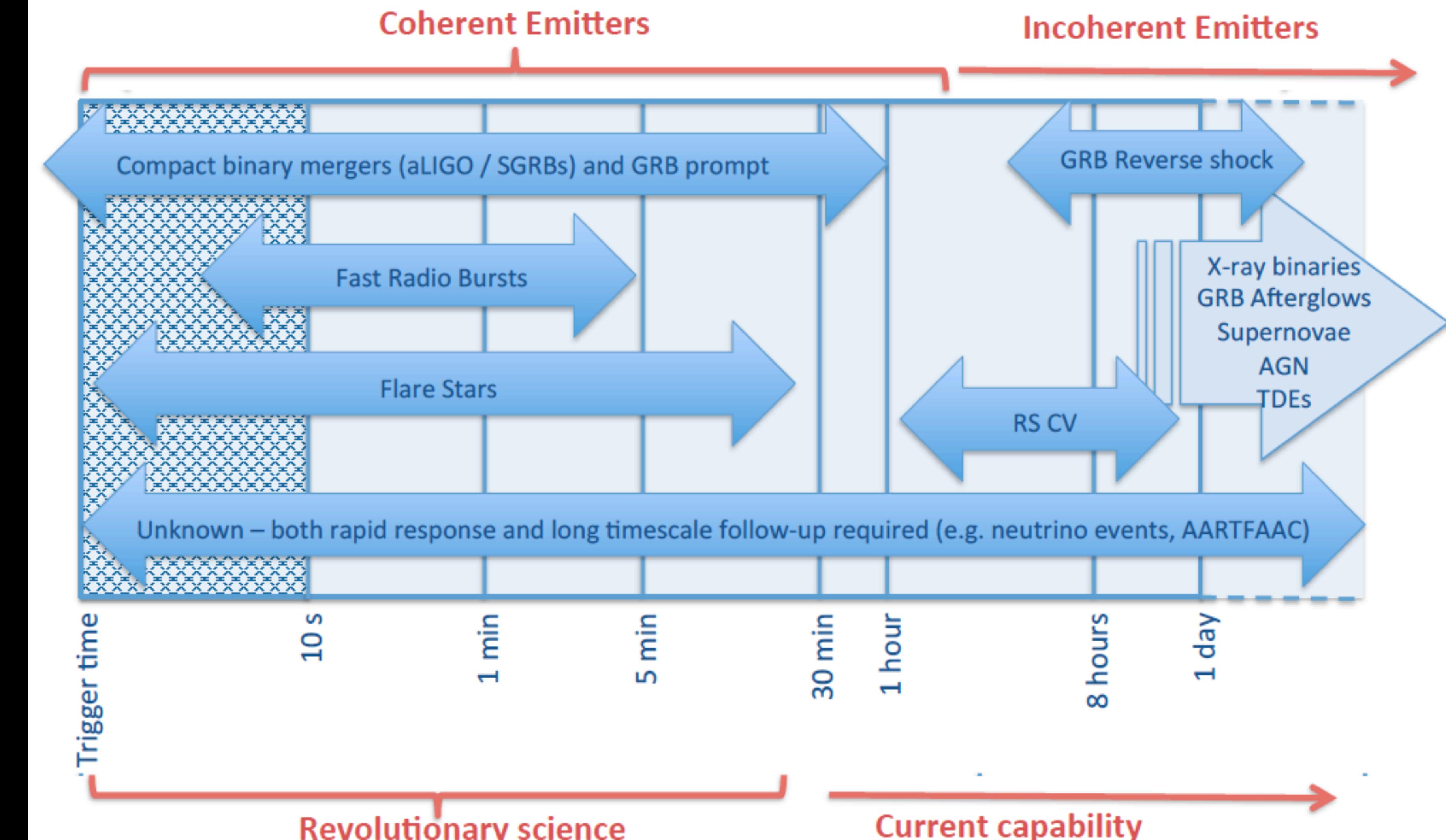
Stewart et al. (2015)

# Explore a range of different timescales for triggered transient searches with LOFAR

## GRB, FRB, GW

### Target transients at low frequencies

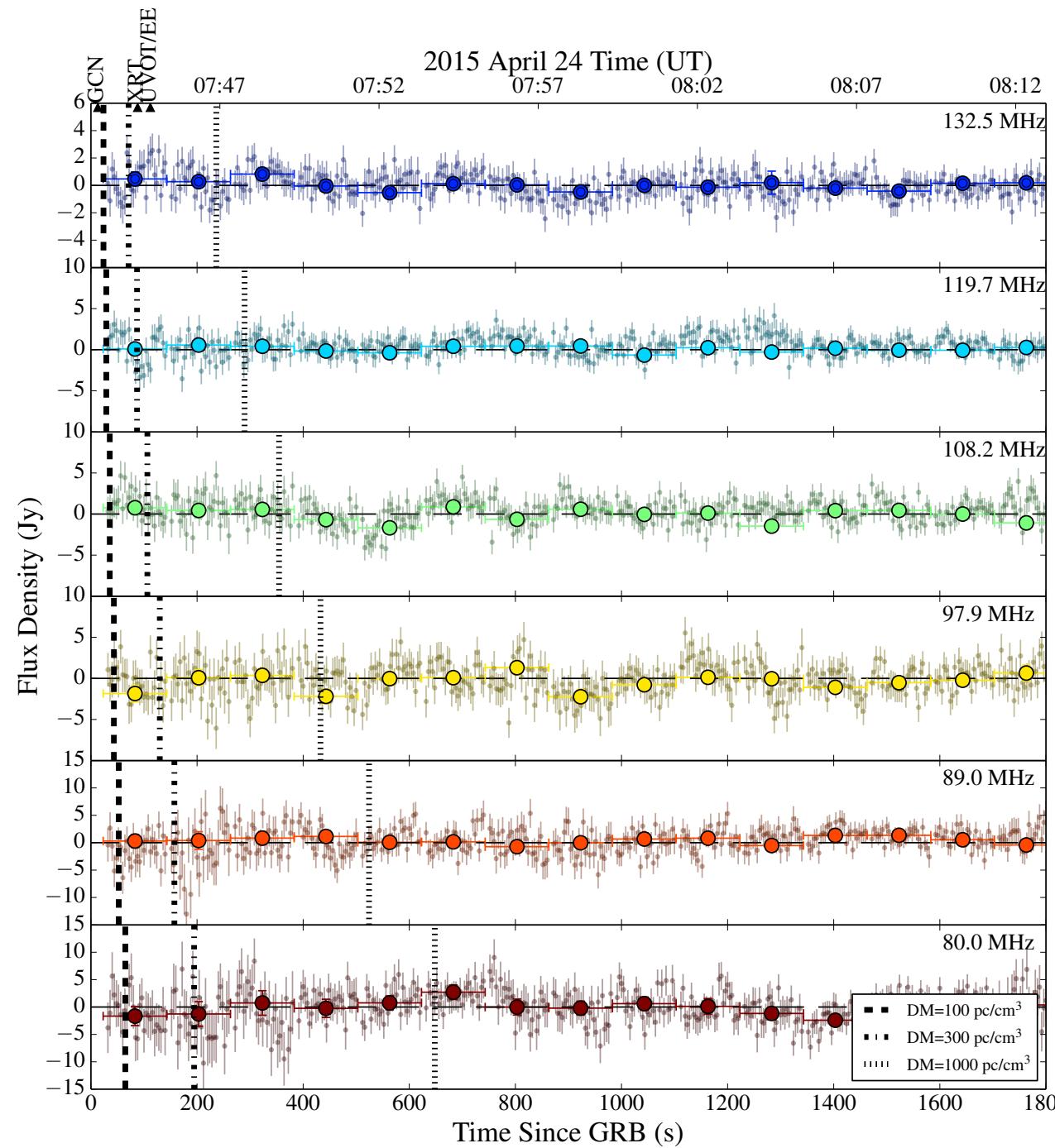
- Fast transients: responsive telescope needed
- No movable parts, MWA already fast response but low spatial resolution, LOFAR not so fast yet (day?) preparing for real time alert!



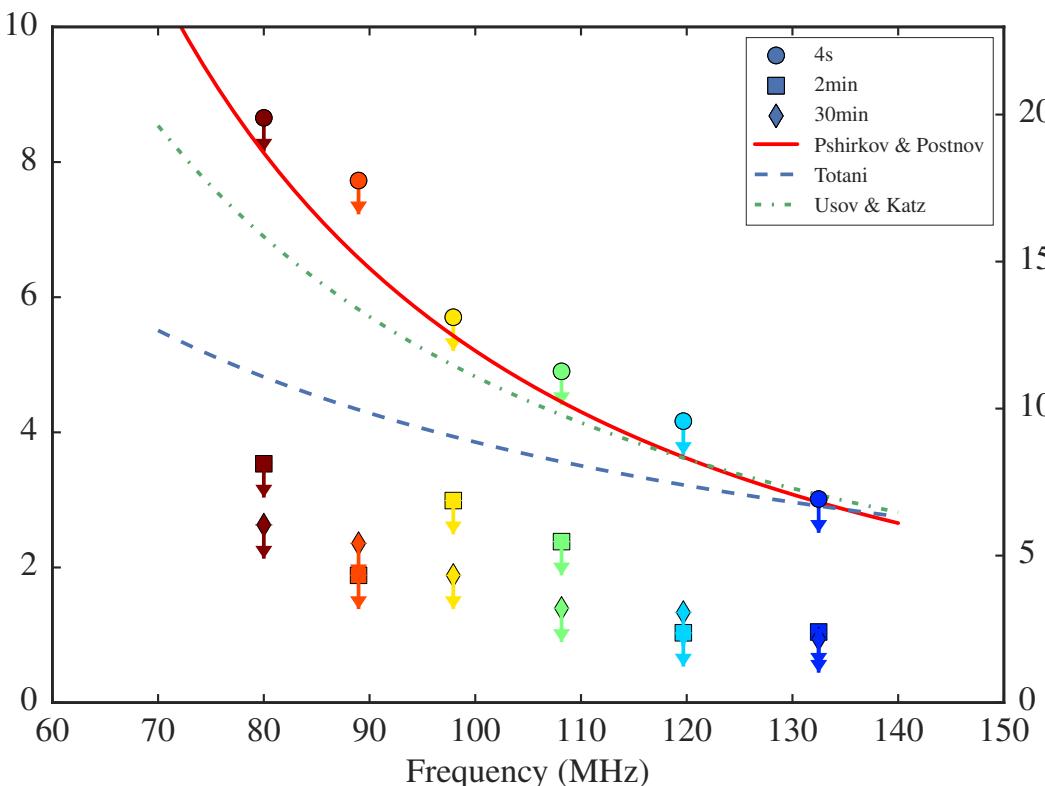
from Antonia  
Rowlinson

# GRB, FRB, GW

## Short GRB 150424A (MWA triggered observation)



- 26 seconds after GRB
- 10 seconds after VOEvent
- Redshift > 0.7



Kaplan, Rowlinson et al. (2015)

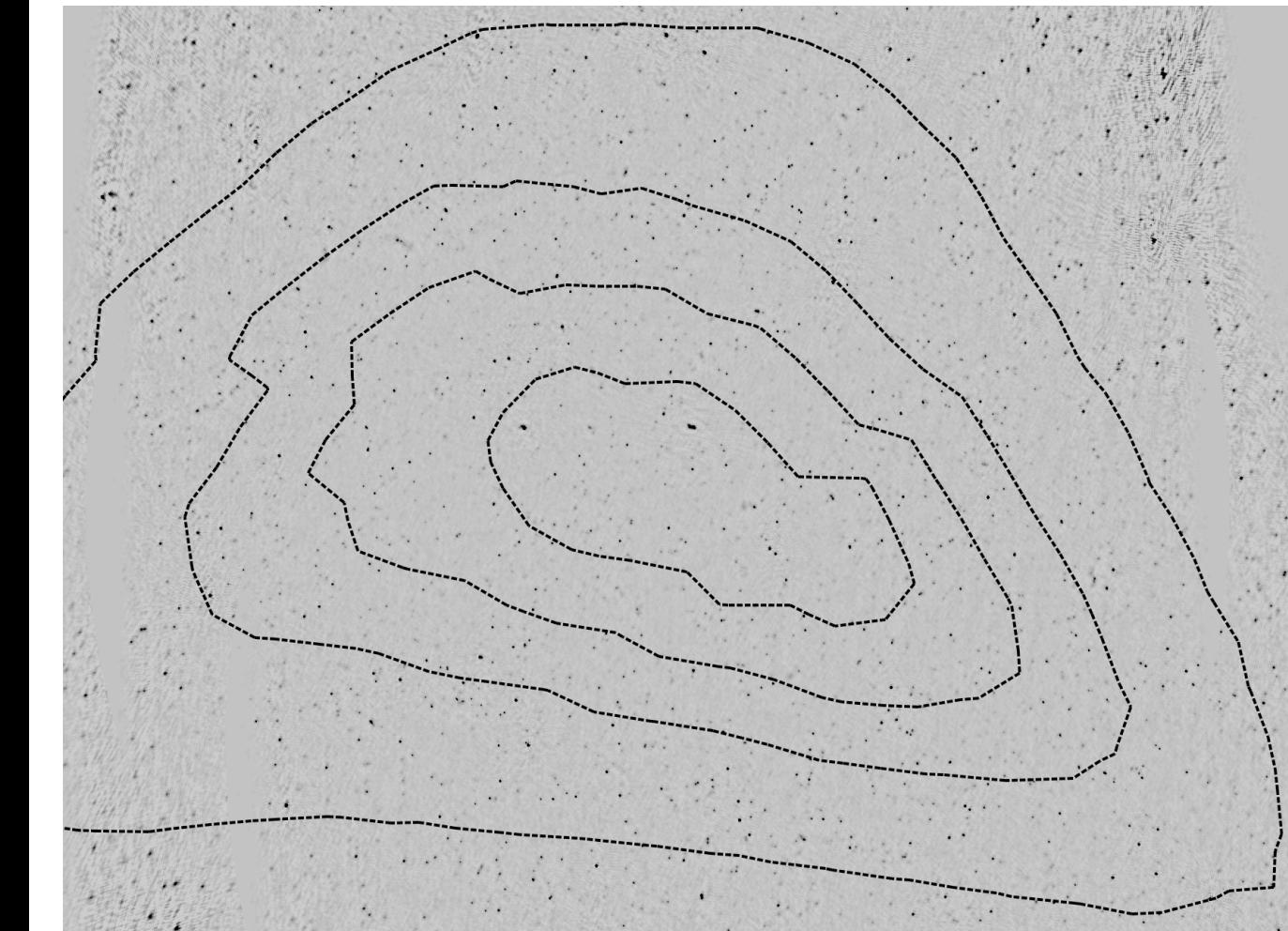
## Limits on prompt radio emission from Short GRB 150424A

Observations started **26s** after the GRB occurred (**10s** after the alert was received)

A telescope with no moving parts **no slew time limitations**

Kaplan, Rowlinson et al. (2015)

## LOFAR follow-up of GW 150914



- Mosaic of 8 SAPs at 145 MHz with a bandwidth of 11.9 MHz
- Resolution 50"
- RMS noise ~2.5 mJy and >2000 sources
- Contours: cWB probability map
- Timescales of 1 week, 1 month and 3 months

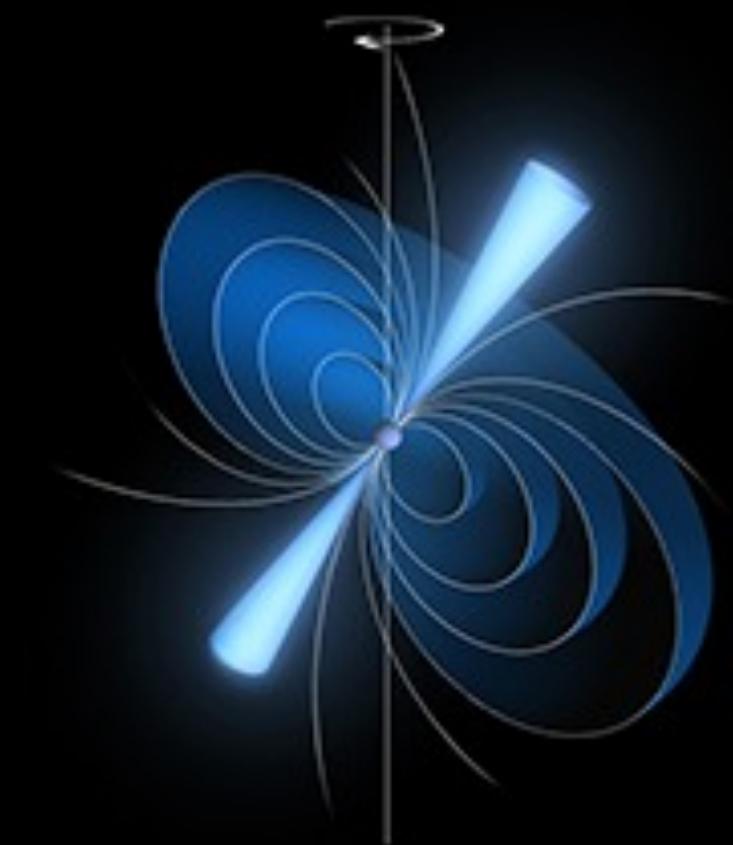
Antonia Rowlinson et al.

# Pulsar magnetospheric mode switching

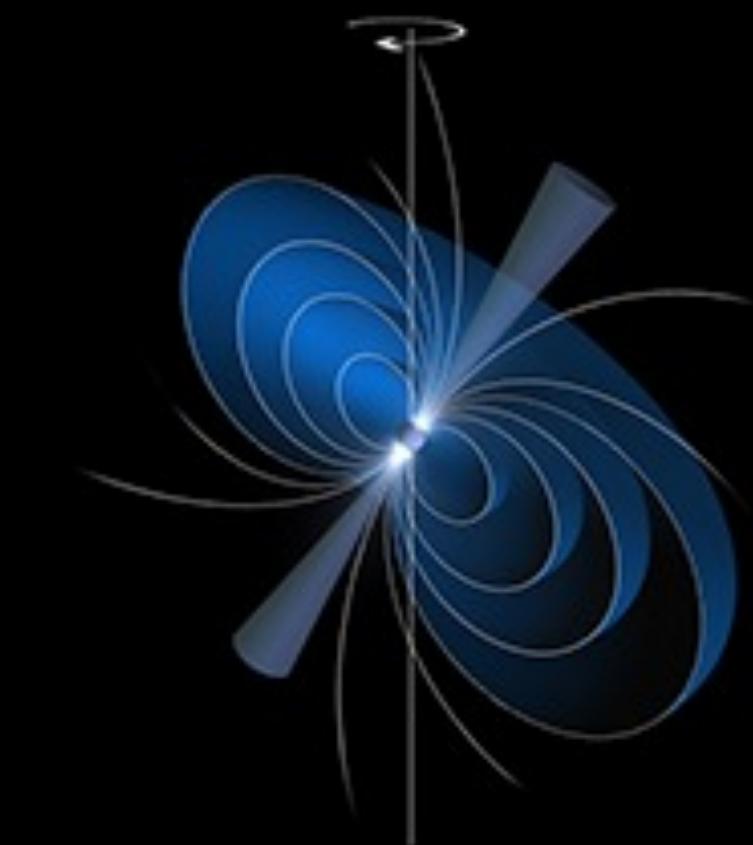
XMM+LOFAR+GMRT

*Hermsen et al. 2013, Science*

**“B-Mode”**

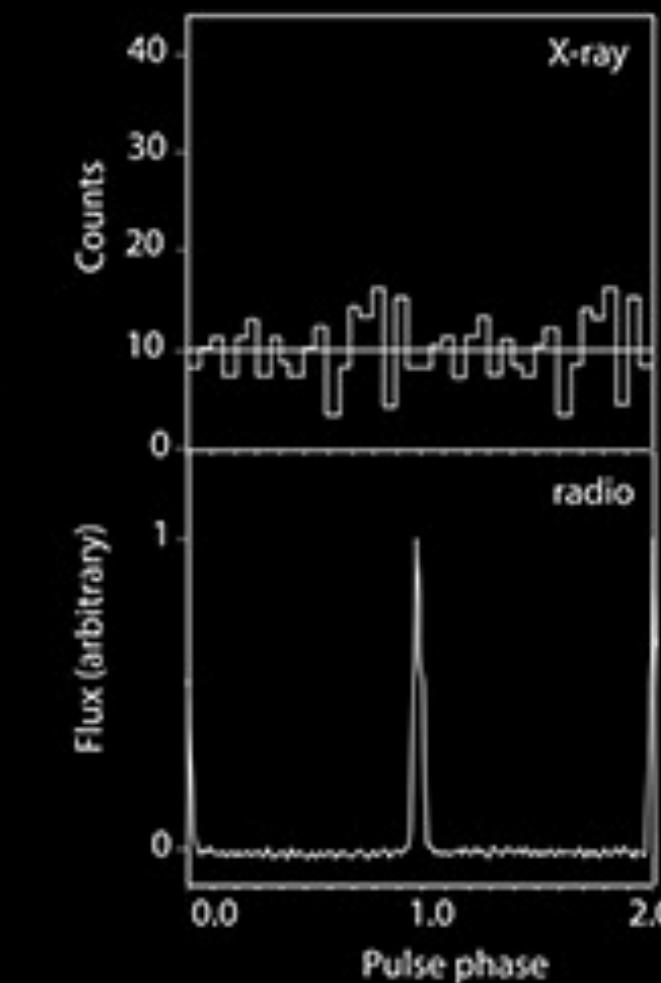


**“Q-Mode”**



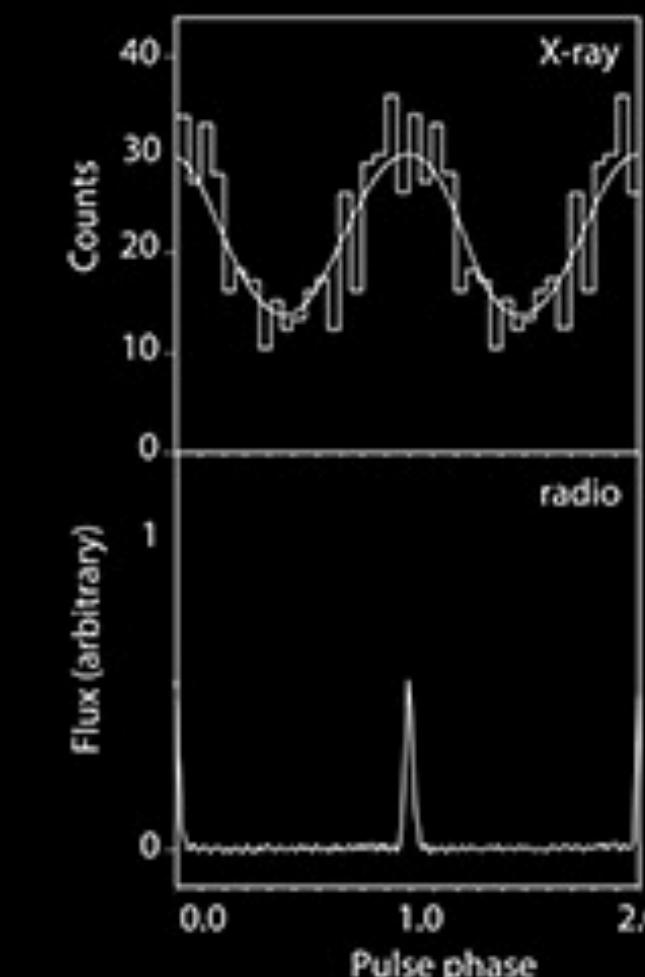
Discovery of correlated  
radio/X-ray mode switching

*Indicating global changes to the conditions in the magnetosphere*



**X-ray dim,  
un-pulsed**

**Radio bright**

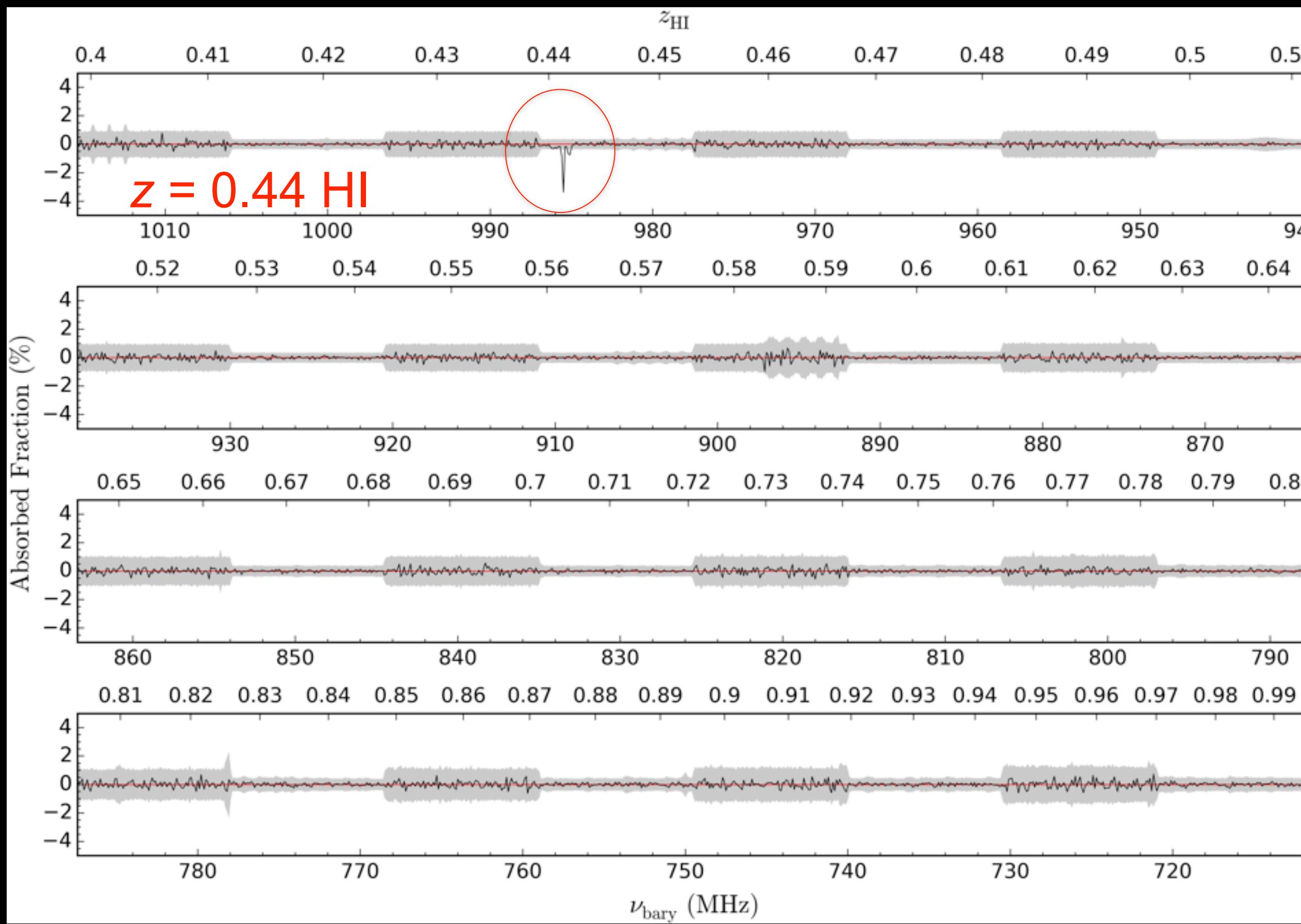


**X-ray bright, pulsed**

**Radio dim**

# Possibilities at GHz frequencies

- ▶ New instruments: Apertif (NL), ASKAP (Aus), Meerkat (SA)
- ▶ Apertif (FoV $\sim$ 8 sqdeg, PIs: T. Oosterloo, M. Verheijen) complementary to LOFAR for continuum and for transients



Apertif system @ WSRT



← example from ASKAP

Allison et al. (2015; arXiv:1503.01265)



# AGN-driven outflows

Tombesi et al. 2012

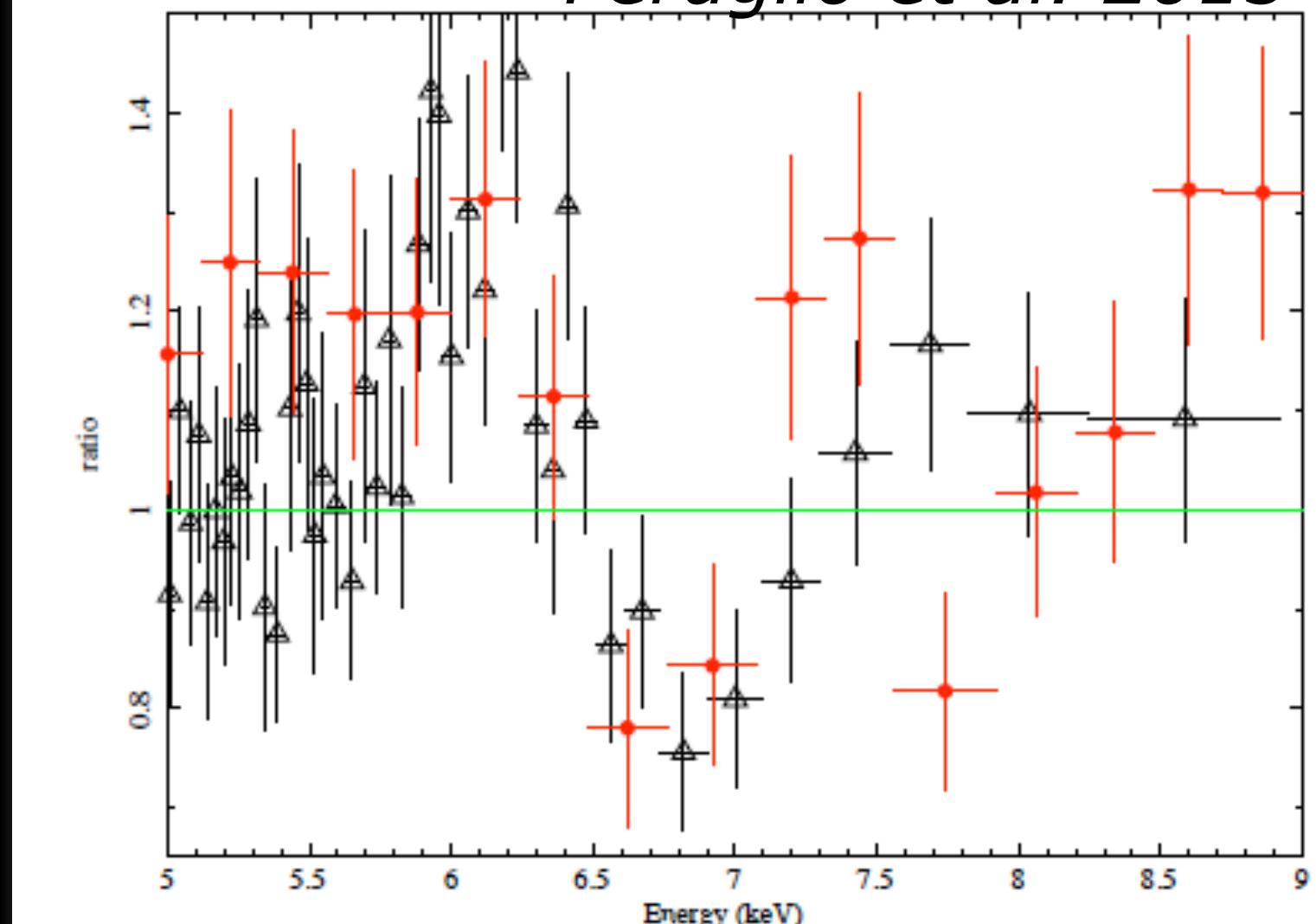


traced by X-ray → winds from accretion disks  
(Tombesi et al., Pounds et al., see Cappi talk tomorrow)  
traced on larger scale by HI absorption?

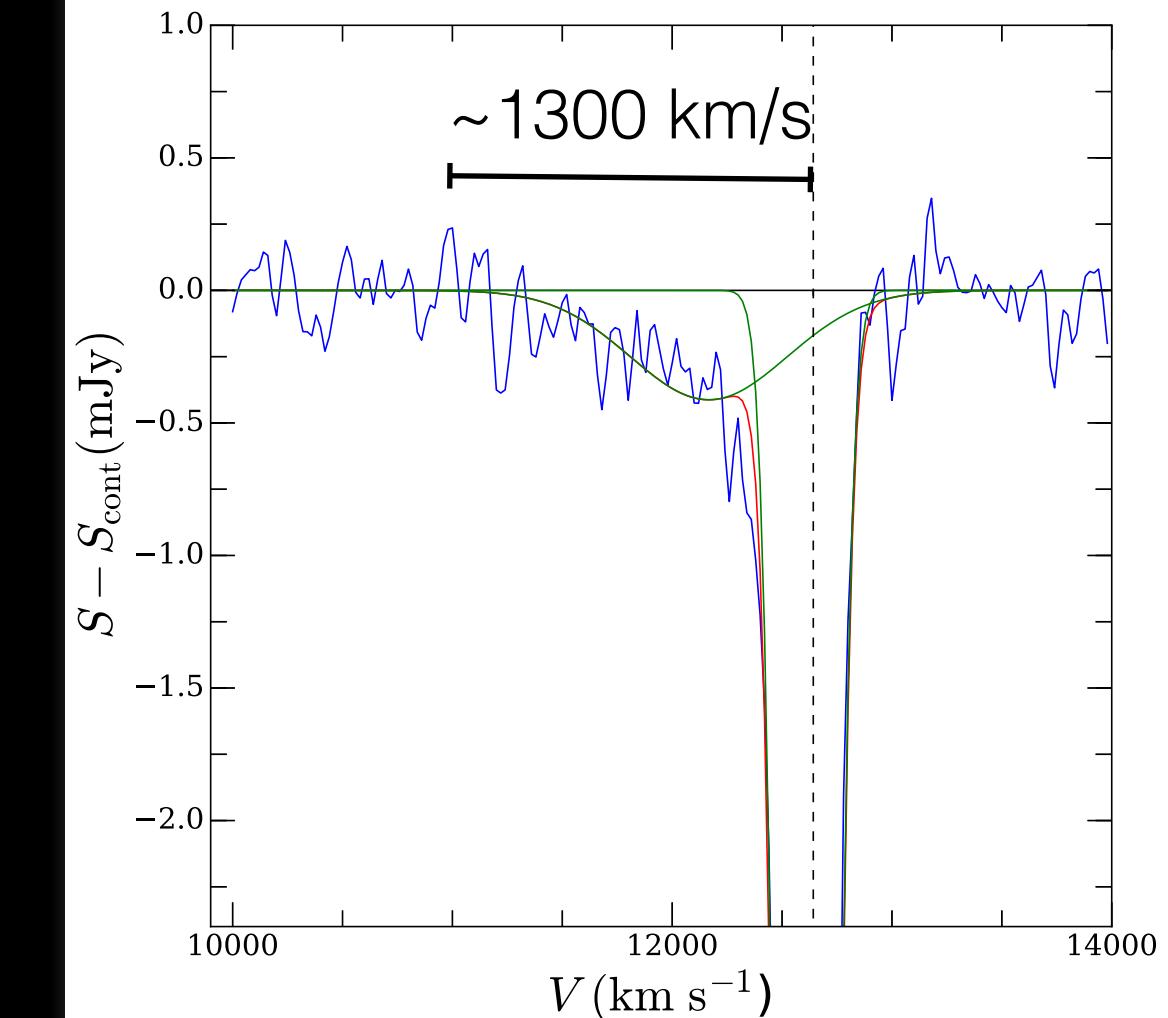
→ large HI absorption surveys may provide targets of outflows for X-ray follow-up

Case of Mrk231

Feruglio et al. 2015



21cm HI absorption



Morganti et al. 2016

- combines all capabilities (and more) of the pathfinders with extra sensitivity
- ongoing preparatory negotiation for Intergovernmental Organisation



Advancing Astrophysics with the Square Kilometre Array

<http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=215>

How will the time allocation work?  
Key Science Projects and based on the contribution of the countries

- Many new possibilities with the present/upcoming radio facilities
- New large surveys in continuum and line
- Transients → in the future we will have a “two-ways” synergy



- SKA 1 is coming: more opportunities, involvement in the preparation of the surveys is welcome!
- A better coordination between radio and X-ray (and in particular XMM) observations may result in larger and less biased samples of interesting objects and provide an important synergy valuable to both communities